# Magneto-Inductive Communication Systems for MCM Operations

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## LONG-TERM GOALS

- Development of seamless on-board communication system for Underwater Bottom Vehicles (UBVs) in the Very Shallow Water (VSW) through Beach Zone (BZ) regime.
- Development of computer models capable of predicting the behavior of electromagnetic propagation in the VSW and Surf Zone (SZ) for both communication and navigation systems.
- Development of the hardware/software to provide field measurements to validate the models in several environments and bathymetric profiles.

## OBJECTIVES

Development of communication technology through: theory development, modeling, and the design, construction and demonstration of equipment and techniques. This task focuses on providing these capabilities to VSW/SZ by constructing six UBVs equipped with the customized magneto-inductive (MI) transceivers and a stand-off control station (SCS). The program's objectives are to establish wireless two-way communication between the SCS and UBVs, and to demonstrate communication among a group of UBVs operating as a network in the VSW-SZ-BZ.

## APPROACH

This is a four-year program in which existing MI technology is being modified and adapted for the UBV application. It involves the design and integration of MI transmitter and receiver components into a UBV supportable MI transceiver, the development of communication protocols and lastly, the demonstration of a group of MI equipped UBVs operating as a network. The focus of Years 1 and 2 is the design, construction and testing of the individual MI communication system components, along with an assessment of their performance in the target operating environment. Years 3 and 4 aim at providing integrated MI transceivers for installation onto a group of UBVs and the assessment of the network in a littoral environment. This program will culminate at the end of Year 4 with a demonstration of the resultant MI communication network via a mock lane search in the VSW-SZ-BZ with six MI transceiver equipped UBVs and one SCS.

## WORK COMPLETED

To date, the following tasks have been completed:

- Modeling of the MI channel in the target operating environment to determine the system hardware requirements.
- Design, construction and testing of hardware for modulating and demodulating AC magnetic fields.
- Assessment of the enhancement effect of magnetically permeable material for both field generation and field detection.
- Empirical verification of MI transmitter and receiver component perfomance.

A key element in the early phase of the work was the preparation of a design analysis in which the field distribution pattern of an AC magnetic dipole in the target operating environment was analyzed[1]. From that, system requirement specifications were derived. The design analysis also considered background magnetic noise levels and the selection of modulation approaches for the MI channel.

Following this initial work, target operating parameters[2] were established for the transceiver components. The choices made were based both on the characteristics of the MI channel and on practical issues related to the physical limitations of the UBV intended as the carrier of the transceiver. Consequently, a decision was made to build the MI transmitters and receivers to operate at a carrier frequency of 1530 Hz and bit rate of 153 bits/sec. The transmitter would be designed to have a magnetic dipole moment of ~110 A-$m^2$, but could be upgraded to ~370 A-$m^2$ by the use of magnetically permeable materials[3-4]. The communication range expected was 150m at 153 bits/sec, with practical ranges to ~400m at reduced bit rates.

A significant effort was directed towards a trade-off analysis for implementation of modems[5] compatible with the telemetry of data using MI techniques. Modems using frequency shift keying (FSK), minimum shift keying (MSK), amplitude and frequency shift keying (AM-FSK), and phase shift keying (PSK) were designed, modeled using computer aided tools, built and tested. The outcome of this work was the identification of the FSK approach as offering excellent results and inherent compatibility with MI technology.

Work was initiated to examine the concept of making the MI transceiver operate with an adaptive bit rate. The initial finding is that there is benefit in this approach because it enables higher data rates to be used when the signal is strong, while providing a basic signaling function when the signal is low; for example, at extreme range. Further work will be performed to carefully analyze the trade-offs before the final approach is decided.

An MI transmitter and ferrite cored dipole antenna with moment of 370 A-$m^2$ and with modulation capability were built, capable of sending data at up to 153 bits/sec. A companion receiver (cored), was developed for data telemetry tests with the transmitter. Both units were extensively tested in the laboratory, prior to carrying out tests on a dry land site and in the VSW.

## RESULTS

Prior to undergoing field tests, the cored MI transmitter and receiver were characterized in the laboratory for use as data telemetry components, and tested successfully with each other for compatibility. Field tests of the MI transmitter (Figure 1) and receiver (Figure 2) were subsequently completed. The tests assessed the moment and field strength versus range for the MI transmitter, and data rate potential versus range for the MI transmitter and receiver, on dry land and in the VSW.

There is a dramatic difference in the power requirement from the previous air-core coil to the present coil which can be largely attributed to the enhancement effect realized from the use of a magnetically permeable ferrite core. In previous work (1998 Halifax Harbor tests), an air-cored coil of the same dimensions of the coil built for this project required a ~100W drive to produce 110 A-m$^2$. The new coil having the magnetically permeable core used only 18W to produce a moment of 110 A-m$^2$, and was capable of achieving a moment of 370 A-m$^2$ on less than 130W. It should be noted that a different wiring configuration aimed at minimizing losses in the windings was employed in the present coil which helped reduce power requirements as well.

***Figure 1. Source Coil Deployed on the Bottom***

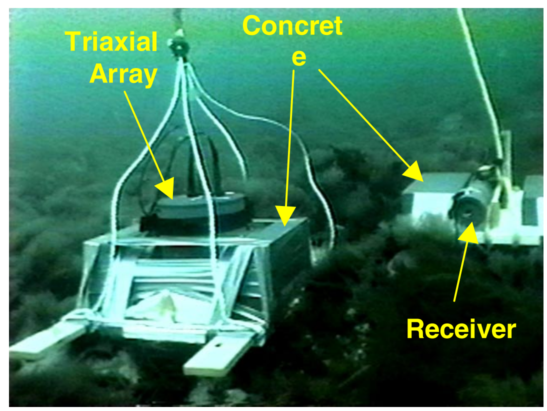


***Figure 2. Triaxial Array And Data Receiver Deployed At Same***

Data blocks of 1024 bits were sent asynchronously from the transmitter using FSK modulation centered at 1530 Hz with a nominal deviation of ±50 Hz and a data rate of 153 bits/second. A 32-bit preamble sent with each block allowed the receiver to synchronize to the bit timing and data framing. The block size was adjustable, but was chosen largely to facilitate bit error rate (BER) measurements. The received data were divided into 8-bit bytes, sent via the serial port to a personal computer, and stored as text files. The sent and received data were compared to determine bit errors.

As the communication range increased, the signal strength and the signal-to-noise ratio (SNR) decreased. The reduced SNR caused the bit error rate to rise. When this occurred, the bandwidth of the receiver was narrowed to reduce the noise and to increase the time for sampling each bit. FSK modulation centered at 1485 Hz (this frequency was chosen because it allowed an expedient manual change of the transmitter frequencies in the field) with a deviation of ±15 Hz and a data rate of 20 bits/second was used. The change in bandwidth allowed reliable data reception out to a considerably longer range of 250m.

Table 1 shows the results of the tests along the nominally constant depth (Track Line 1), and Table 2 shows those along the inclined bottom (Track Line 2). The columns correspond to each station along the track line (50m intervals). With the use of a triaxial receiver array (Figure 2), magnetic field measurements were used to study the field distribution pattern and to establish the optimum orientation for the data receiver. This was determined to be in the x-axis (horizontal along the axis of the transmitter antenna) which was also the direction of the track lines. The flux density in the x direction, Bx, indicates the signal strength and the spectral field noise (total of x, y and z components) is included as an indication of the noise. The last two rows are for the bit error rate tests at 153 bits/sec and 20 bits/sec. When over 10,000 bits were recorded and there were no errors, a "no errors" entry was made with the assumption that the BER would be $10^{-4}$ or better.

The tests confirmed that through using a ferrite clad transmitting coil to achieve a dipole moment of 370 A-$m^2$, data communication at rates >150 bits/second can be achieved at ranges beyond 150m. In addition, the tests demonstrated that at lower bit rates (e.g., 20 bits/sec) communication was possible to 250m. From the test results, it is anticipated that an even narrower bandwidth receiver would be able to communicate over a range greater than 300m. Conversely, by employing a wider bandwidth receiver, we expect data rates exceeding 150 bits/second (i.e., 300, 600 bits/second) may be achieved at shorter ranges (i.e 50-100m). We are developing an adaptive modem capable of adjusting its own bandwidth in response to the signal strength being received. This will allow for reliable communications over a greater range by narrowing the bandwidth as the received signal strength decreases. The trade-off is a reduced data rate at longer ranges.

**Table 1. Data Reception During Halifax Harbour Tests: Track Line 1**

| **RANGE** | **50m** | **100m** | **150m** | **200m** | **250m** |
|---|---|---|---|---|---|
| **Station** | 11 | 12 | 13 | 14 | 15 |
| **Depth** | 8.2 m | 8.2 m | 8.8 m | 10.4 m | 9.8 m |
| **RX orientation** | X | X | X | X | X |
| **Measured CW field (T)** | Bx 1.30 nT | Bx 16.4 pT | Bx 5.25 pT | Bx 1.15 pT | Bx 0.67 pT |
| **RMS noise** | - | .054 pT/√Hz | .078 pT/√Hz | - | - |
| **BER: 153 bits/s** | no errors | no errors | BER=0.011 | - | - |
| **BER: 20 bits/s** | - | - | no errors | BER≈0.01 | BER=0.017 |

**Table 2. Data Reception During Halifax Harbour Tests: Track Line 2**

| **RANGE** | **50m** | **100m** | **150m** | **200m** | **250m** |
|---|---|---|---|---|---|
| **Station** | | 21 | 22 | 23 | |
| **Depth** | | 5.2 m | 3.7 m | 2.4 m | |
| **RX orientation** | | X | X | X | |
| **Measured CW field (T)** | | Bx 70.8 pT | Bx 25.7 pT | Bx 8.8 pT | |
| **RMS noise** | | .052 pT/√Hz | .36 pT/√Hz | - | |
| **BER: 153 bits/s** | | no errors | no errors | no data | |
| **BER: 20 bits/s** | | - | - | no errors | |

## IMPACT/APPLICATION

To date, no wireless communications channel has been found capable of providing reliable, seamless coverage of the entire VSW-SZ-BZ theatre. The successful development of the UBV MI transceiver will provide the US Navy with a reliable remote command and control channel for littoral MCM activities. The research and development being performed under this task also lends itself to numerous other naval applications where traditional wireless communication technologies are ineffectual or where direct cabling is seen as being neither practical nor desirable.

## TRANSITIONS

Technology developed in this task is planned for transition to the VSW MCM 6.4 Program.

In view of other potential transitions, VSWMCMDET PMSEOD NAB Coronado and NSWC/IHD have been briefed, as well as DARPA, NAVSEA and NSWC/CD. All have expressed an interest in finding a reliable wireless communications, navigation and firing device channel able to provide seamless coverage of the VSW/BZ regime.

## RELATED PROJECTS

There are two ongoing projects sponsored by ONR that are related to this effort:

*Magneto-Inductive Navigation (MINAV)* - a joint research effort among CSS, FMI, and MISL. This task focuses on the development of a MI navigation system. Recently, the group successfully completed the Phase II of the STTR program, Topic Number N97T005.

*Magneto-Inductive Firing Device (MIFD)* - a joint effort among CSS and MISL. This task focuses on the development of a standoff command and control of firing devices.

## REFERENCES


1. Magneto-Inductive Systems LTD, 1999. Design Analysis, July.

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